

Proceedings of the American Academy of Arts and Sciences.

VOL. 64. No. 6.—FEBRUARY, 1930.

**THE REFLECTING POWER OF SOME SUBSTANCES IN
THE EXTREME ULTRA-VIOLET.**

BY PAUL R. GLEASON.

THE REFLECTING POWER OF SOME SUBSTANCES IN THE EXTREME ULTRA-VIOLET.

BY PAUL R. GLEASON.

(Communicated by Theodore Lyman.)

INDEX.

| | | |
|-------|--|-----|
| I. | Introduction..... | 92 |
| | Previous work..... | 92 |
| II. | Apparatus..... | 93 |
| | Optical arrangements..... | 93 |
| | Vacuum spectroscope..... | 94 |
| | Grating and grating mounting..... | 94 |
| | Plateholder and mirror assembly..... | 95 |
| | Slits..... | 95 |
| | Discharge tube source..... | 95 |
| | Capillary valve..... | 97 |
| | Sectored disk assembly..... | 98 |
| | Pump and vacuum conditions..... | 99 |
| | Gases for source radiation..... | 100 |
| | High voltage generator..... | 100 |
| | Photographic plate..... | 100 |
| | Photometer..... | 100 |
| III. | Experimental methods..... | 100 |
| | Preparation of mirrors..... | 100 |
| | Adjustments of mirrors..... | 103 |
| | Exposure of the photographic plates..... | 104 |
| | Photometric measurement of plates..... | 105 |
| IV. | Photographic photometry..... | 106 |
| | Correct use of photographic plate..... | 106 |
| | Reciprocity condition and its failure..... | 106 |
| | Justification for use of Intermittent Sector..... | 107 |
| V. | Calculations..... | 108 |
| VI. | Sources of Error..... | 109 |
| VII. | Results..... | 110 |
| | Photographic photometry with the oiled photographic plate..... | 110 |
| | Reflecting power results..... | 112 |
| | Metals..... | 112 |
| | Other materials..... | 119 |
| | Table of results..... | 122 |
| VIII. | Conclusions..... | 123 |

INTRODUCTION.

IN an earlier paper, the author¹ has presented the results of his work on the reflecting power of a number of substances to light of very short wave-lengths. It is intended here to add the results on three more mirrors and to describe in more detail the apparatus and methods used.

A total of twenty-five mirrors of seventeen different materials have been investigated. The light employed varied in wave-length from 585 Å to 1800 Å.

Previous Work.—Heretofore results on the reflecting power in this region of wave-lengths have been obtained either by qualitatively comparing the reflection of one substance with that of some standard mirror, or without resolving the light and taking advantage of the full intensity of the source over a wide range of wave-lengths, to get average numerical results.

Gardner² obtained qualitative results on nine metals for wave-lengths between 1700 Å and 1025 Å. He illuminated the slit of a vacuum spectrograph by light reflected at 45° from both speculum and the mirror under investigation. The spectrum produced was double; i. e. the light from each mirror produced in closely adjacent positions its respective spectrum. Since the two mirrors were simultaneously illuminated, any fluctuation in intensity of the source did not affect the relative intensities of the reflected spectra. Thus for each wave-length present the comparison with speculum could be made and was carried out for silicon, platinum, stellite, copper, nickel, gold, steel, silver, and aluminum. Numerical results were impossible because of the photometric characteristics of the Schumann plate. Absolute values necessarily would depend upon the mirror used as standard and the numerical value of its reflecting power at the various wave-lengths.

Pfund³ studied speculum, silver, gold, platinum, quartz and glass. Numerical results were obtainable through the use of a thermopile. His source was a discharge in hydrogen so excited as to give principally the atomic spectrum. Its total radiation was first reflected by a concave glass mirror, and then by the mirror under investigation. He verified the fact that there was no radiation present of wave-length between 1300 Å and about 3000 Å by observing that a glass screen in the light beam reduced the response of the thermopile by the same amount as a fluorite screen. He thus could correct all readings for light of wave-length longer than 1300 Å by interposing

the glass screen. Numerical values were obtained by first evaluating the reflecting power of glass and then substituting the other mirrors. The data obtained were for the wave-lengths between 912 \AA and 1216 \AA , principally the Lyman series. Undoubtedly the 1216 \AA line predominated, although an appreciable effect from the 1026 \AA line would be expected.

Pfund⁴ has used another method by which he was able to trace the variation of the reflecting power with wave-length. Working photographically, he compared the spectrum obtained in the usual way with one obtained from light produced in a second branch of the same discharge tube which shone at 45° on the mirror under examination and thence to the slit of the same spectrograph. These results have not been numerical, but have served to discover maxima in the reflecting power of certain crystalline substances at wave-lengths just longer than the absorption band wave-length demanded by dispersion formulae.

Lewis and Hardy⁵ did not resolve their light but used photoelectric cells whose targets had a long wave-length limit of photoelectric action near 1900 \AA . This eliminated the necessity of screens, in that light affecting the cells was of wave-length long enough to go through quartz but not longer than the photoelectric limit of the target. Since they used a quartz mercury arc as source, their results refer principally to the 1849 \AA mercury arc line.

Hulburt⁶ performed some very important experiments on the reflecting power of metals. His work did not, however, extend into the region of primary interest here, as he worked in the near ultra-violet between 3800 \AA and 1850 \AA . He used a concave grating to analyze the light, and a photoelectric cell to measure intensities. Numerical values of the reflecting power were possible because the cell could be placed to receive not only the spectral lines formed in their usual positions, but also the same lines after reflection at 18° from the mirror under investigation. This was accomplished by turning the entire cell assembly through an angle of 144° and simultaneously bringing the mirror into position. Hulburt measured the reflecting power of twenty-eight metals by this method.

II. APPARATUS.

Optical Arrangements.—The general optical arrangements of Hulburt's were adapted to a vacuum spectrograph for the measurement of the reflecting power at the shorter wave-lengths. In a schematic way, Fig. 1 shows the optical features of the apparatus.

The light from a direct current discharge passed through the slit S to the grating G where it was reflected and analyzed, forming the spectrum on the circle through the slit and the surface of the grating. Certain of the first order lines, as a and b , fell on the photographic plate at P . If a mirror at M was interposed at 45° to the light beam, and the plate turned through 90° about the point O in the surface of the mirror, then the spectral lines a and b fell at a' and b' upon the plate in the new position P' without change of focus.

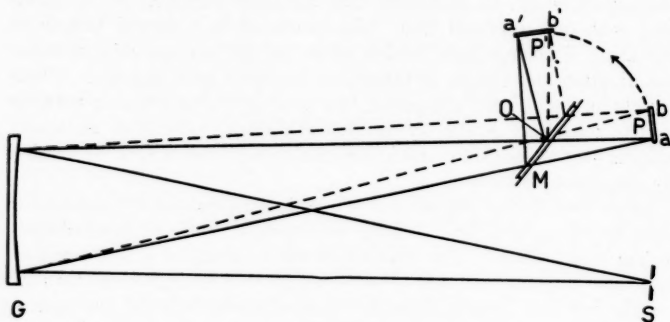


FIG. 1.

Vacuum spectroscope.—The details of the construction of the external vacuum chamber were roughly those described by Prof. Lyman.⁷ However, the main drawn brass tube was closed at both ends by chambers cast in bronze. At one end the bronze chamber housed the grating and its mounting and was closed by a brass plate. At the other end the chamber contained the plateholder and mirrors. This one was closed with a hat-shaped cover carrying the four vacuum-tight tapers for external controls.

Grating and grating mounting.—The grating was of 50 cm. radius so that a short light path with small absorption in the spectrograph could be had. It was ruled on speculum metal at Johns Hopkins with 15,000 lines to the inch. The effective ruled surface was 4.5 cm. high by 8 cm. wide. This grating was carried on a carefully constructed mounting. In addition to the eight adjusting screws to provide usual adjustments, a divided circle coupled to a micrometer head enabled the operator to determine the position of the grating to better than a minute of angle. This was expedient because the

narrow plate used could record but a 450 \AA width of spectrum. Thus the grating had to be accurately turned to give known wavelength regions on the plate. Not only could these settings be made precisely and read through a window in the cover plate, but they could be made without disturbing the vacuum by turning a vacuum-tight taper mounted on the cover plate.

Plateholder and mirror assembly.—A screw mechanism to raise and lower the plateholder and thus to provide for as many as fifteen exposures on a single plate was an important feature of the spectrograph. Similarly, the mounting M for the mirrors was raised and lowered by a screw so as to accurately place either of three mirrors in the optical path or to remove them altogether. The motion of the plateholder from position P to position P' was simply taken care of by mounting it on a small bearing above M whose axis was vertical and passed through O . In addition to these three adjustments, a fourth was essential for focusing the plate. In fact, each angular position of the grating required a different position of the plate for focus. This was provided by the motion of the entire plateholder assembly along the axis of the instrument. A divided circle visible through a window indicated the position in regard to focus.

Each of these adjustments was made possible from the outside of the vacuum chamber by a vacuum-tight taper. This arrangement consisted of a steel inner taper carefully lapped into fit with a brass outer taper. The joint was made vacuum tight with stop cock grease.

Slits.—The slit ordinarily used was of the type described by Prof. Lyman.⁸ Another design was necessary for the latter part of the work and will be described later (Fig. 4). On the average the slit was adjusted to a width of 0.04 mm. and a height of 0.20 mm.

Discharge tube source.—The source of light used was the direct current discharge in gases. The internal capillary tube exactly as used by Prof. Lyman⁹ and constructed of quartz was employed during a large part of this work. A satisfactory substitute was constructed of pyrex as shown in Fig. 2. The opening S was cemented onto the slit of the spectrograph with the end of the internal capillary to within about 2 cm. of the slit. The inlet G served to admit the gas and to continuously replenish the supply.

The electrodes E_1 and E_2 were spirals wound from tungsten wire. The tungsten lead-ins were protected from the discharge by the quartz sleeves Q . Thence they passed through the inverted pyrex seal I to the lead tips L . These lead-in assemblies were demountable, being sealed into side tubes with De Khotinsky cement.

The currents possible with a pyrex tube were about as high as with the quartz tube of the former design. The usual condition of operation was at 900 volts and a gas pressure which permitted 50 m.a. current to pass. This current has been pushed to 60 m.a. with safety even for a period of five continuous hours of service. A small electric fan was required to protect the seals from overheating.

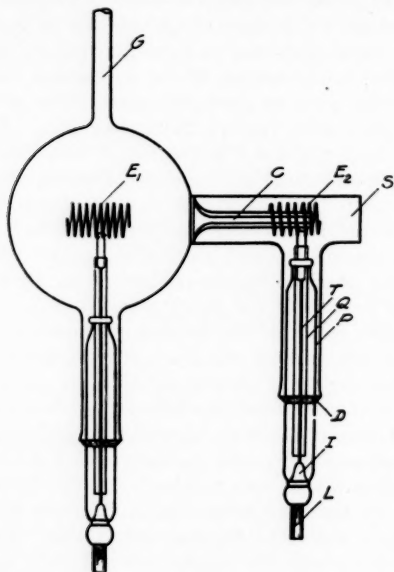


FIG. 2.

It is well known that the direct current discharge can not be started in a tube unless either the pressure is increased beyond operating conditions or the initial voltage increased. Neither method is desirable where great constancy is sought in the running conditions of the tube. The difficulty was solved by the use of a third electrode E_3 placed anywhere in the bulb with E_1 but insulated from it. Then to start the discharge, the operating direct voltage was supplied across E_1E_2 while across E_2E_3 the voltage from a high tension transformer was applied. The latter easily excited a discharge which the direct voltage could maintain.

The Capillary Valve.—Since there was constant leakage of gas from the discharge tube into the spectrograph through the slit, there had to be replenishment through *G*. Furthermore to insure a constant intensity of light it was fundamentally necessary to regulate accurately the flow of gas into the tube. The all-metal capillary valve shown in Fig. 3 accomplished this purpose. It consisted essentially of an inner taper T_1 of steel carefully fitted to and lapped into contact

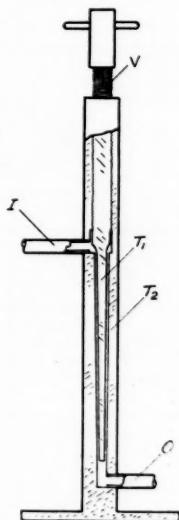


FIG. 3.

with the outer brass taper T_2 . The inner taper was then fastened to the end of a vacuum tight screw and moved vertically with respect to T_2 , thus varying the leak over wide limits. The vacuum screw was cut in brass at a half millimeter pitch. Care was taken in the cutting of the thread, both for the screw and nut, so that they fitted each other closely over the entire contour of the thread. With a four centimeter nut and a little stop cock grease worked into the thread, the valve was tight.

Sectored disk assembly.

To provide means for changing by known amounts the intensity of the light passing through the slit, the attachment shown in vertical section in Fig. 4 was used. This could be substituted for the slit first used without changing the focus of the instrument as a whole.

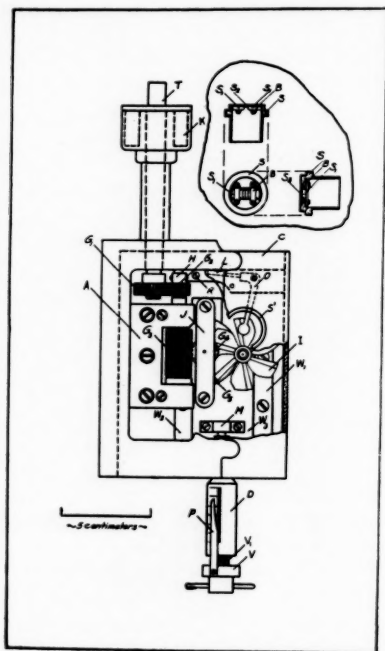


FIG. 4.

The reduction in intensity was accomplished by the rotation, just behind the slit, of the variable aperture sectored disk *I*. The actual disk had fifteen apertures for cutting the intensity to values from 50% to 2.5% of the incident light. It was desirable to produce sixty flashes of light per second which required that the disk revolve ten times each second.

The disk was mounted on the end of a small shaft on which was placed a 20 tooth spur gear, which meshed with the 100 tooth spur gear G_5 . G_5 was on the same shaft with G_4 , a spiral gear meshing with the spiral gear G_3 . In turn, G_3 was on the same shaft H with G_2 a spur gear meshing with G_1 and having a 1:2 ratio to it. G_1 was mounted on the end of a vacuum-tight taper T , which was belted through a gear reduction to a motor so that T would turn once a second. The taper T held the vacuum over many continuous hours of turning. Stop cock grease rich in vaseline served both as lubricant and vacuum seal.

Other mechanism was necessary to permit the vertical motion of the disk so as to bring desired apertures opposite the slit. For this I , G_4 , G_5 and J which carried the shaft of these latter gears were all mounted on the plate W_3 . This plate moved vertically in the fixed guiding ways W_1 and W_2 . This motion was actuated by the vacuum screw V_1 turning in its nut D . In fact, the tip of V_1 pushed directly against M which was rigidly attached to W_3 . Obviously the spiral gears G_3 and G_4 remained in mesh for all settings of the disk. The precise position vertically was read off the scale on D by means of the pointer P .

A magnetic shutter for starting and stopping the exposures was fastened to the back plate of the case to this assembly with a single screw. The armature L easily moved the shutter arm O about the pivot. Contrary to the drawing, the circular tip was behind the disk.

Since the disk was not more than three millimeters from the slit, it is easy to see that the individual steps of one millimeter each on the disk were ample. The whole disk was thus four centimeters in diameter. The disk was cut on a precision milling machine whose accuracy even on this small scale must have been at least to 1%. Careful measurements of the disk showed this to be true.

This assembly occupying as it did the position formerly taken by the simple slit mounting, required a special type of slit as shown in the figure. In this case the slit assembly fitted into the recession S' and had its jaws at the same distance from the grating as the other type of slit. In the newer slit the jaws S_1 were adjusted to the proper opening S_2 and then clamped into position with the bar clamps B . This arrangement facilitated the setting of the jaws of the slit.

Pumps and vacuum conditions.—With suitable drying tubes inserted, the spectrograph was connected to a Cenco Hyvac pump.

This pump was able to exhaust the system in about twelve minutes to a point where the high tension transformer could not excite a visible discharge in the test discharge tube. In spite of the many moving and stationary joints the pressure increased to only about a centimeter of mercury after leaving the apparatus idle for a week.

Gases for source radiation.—Commercial nitrogen and commercial oxygen (Matheson) were stored in liter flasks connected to the apparatus. An electrolytic generator provided hydrogen. Helium, which had been carefully purified for spectrum work, was obtained in a gasometer from Prof. Lyman's supply. In each case the gas was dried over phosphorus pentoxide and passed through a U-tube in liquid air before entering the discharge tube.

High voltage generator.—The voltage necessary for the direct current discharge was generated by an Electric Specialty Co. motor-generator. The motor was a 550 volt, three phase induction motor and the generator compound wound (1500 v) so the resulting voltage was very constant. The voltage could be closely regulated by a sliding contact rheostat in series with the field rheostat.

Photographic plate.—The photographic plate ordinarily used was the Cramers Red label, lantern slide plate. These were cut to size, and sensitized to the extreme ultra-violet by dipping in a solution of 10 drops of Nujol¹⁰ in 40 c.c. petroleum ether. After exposure the plate was washed in petroleum ether and developed in the usual way.

Photometer.—The thermocouple photometer¹¹ of the Students' Astronomical Observatory (Harvard) was used for the measurement of the plates through the courtesy of Prof. Stetson. To the instrument described in the reference has been added a slit suitable for working with spectral lines, and a moving stage with micrometer screw motion to facilitate the placing of the various spectral lines over the photometer slit.

III. EXPERIMENTAL METHODS.

Preparation of Mirrors.—In order that data on the reflecting power be significant, they should refer to clean surfaces of the pure material which have been formed to optical flatness and highly polished. These conditions are difficult to meet. Possibly the simplest method with the metals is to resort to cathodic sputtering. By this method, providing the deposit is formed on a surface that is clean, flat and highly polished, the deposit itself is in general an excellent mirror.

A thin, transparent film must not be used as its reflecting power would probably be too low. On the other hand, a thick film is inclined to peel. Hence, the most useful sputtered mirror is one which is intermediate in thickness.

The sputtering apparatus employed was designed to eliminate as far as possible contaminating vapors from the wax and greases used in sealing. The distance from the cathode to the mirrors to be coated was about 5 cm. The anode was of aluminum and so shielded that the a.c. source used for the sputtering would not permit the depositing of the aluminum on the mirror. So many variables are involved in the process that the time required to sputter a mirror is not of much significance. However, the approximate time is indicated.

Optical glass which was taken from plano-flat spectacle lens blanks from the American Optical Co., was cut to the 1 cm. by 3 cm. size for the mirrors. These had to be thoroughly cleaned to insure a good sputtered surface.

The opacity (i. e. the percentage of light absorbed in transmission) for most of the sputtered mirrors was measured. This was done on the thermocouple photometer employed in the measuring of the photographic plates. The readings did not in every case check rough visual measurements, but any discrepancy could be explained by the fact that the light source in the photometer undoubtedly was rich in infra-red radiation.

Other mirrors were prepared by polishing a solid block of the material. The methods used are described below.

Aluminum.—Although aluminum does not sputter readily, it was possible to prepare a mirror of 94% opacity during the course of eight hours sputtering in a residual atmosphere of argon. This was the only mirror sputtered with a direct current discharge.

Beryllium.—A specimen of this metal procured from the Beryllium Corporation of America was used for the sputtering. The first day's efforts were in vain, but it was finally possible to get a 98.5% opaque film. Once started, the sputtering proceeded fairly rapidly in the presence of argon.

Brass.—A piece of brass was machined* to approximate flatness and then lapped to an excellent polish and optical flatness on a dry jasper lap which had been previously made accurately flat.

*Chromium.**—A piece of carbon tool steel was machined into approximate shape and after hardening was ground and lapped on a tin

* I am indebted to Mr. David Mann for the polishing of this mirror.

lap with fine emery and sperm oil. It was then polished with diamantine† and alcohol on a boxwood lap. Chromium was electrolytically deposited on this steel mirror. The chromium surface presented a rather milky appearance so was polished lightly with diamantine on boxwood.

*Cobalt.**—The cobalt mirror was prepared from a solid piece of the metal obtained through the courtesy of Prof. Hall. It was ground and then lapped on a tin lap with fine emery and finally polished with diamantine on boxwood.

Fluorite.—A piece of a fluorite window was used without retouching as a mirror. It was from Zell in Baden, and had been polished by Thomlinson in 1925. It is difficult to produce a good optical surface on fluorite and doubtless this one had been scarred in its use as a window. At any rate the surface had a large number of pits and scratches in it.

Glass.—The glass mirror used was simply one of the blanks described for use in sputtering. The American Optical Company reports that this glass has an index of refraction of 1.523 for some wave-length in the visible.

Gold.—The mirror of gold was sputtered in about four hours to an opaque film. The gold had a tendency to peel from the glass because of the thickness.

Nickel.—Nickel also sputtered easily to a 96.7% opacity in about five hours.

Platinum.—The platinum surfaces were prepared with about three hours sputtering to a 99% opacity. Three different sets of sputtered surfaces were prepared.

Quartz.—The crystalline quartz mirror was prepared by cutting a flat window of that substance obtained from Ph. Apffel Co. (New York). The orientation of the crystal axes with respect to the reflection surface is unknown. The fused quartz mirror was cut from a fused quartz window that had been freshly repolished by the Jones and Hewett Optical Company.

Silver.—Silver was deposited chemically to an opaque film on optical glass to form the silver mirror.

Silicon.—No solid piece of this material could be found which was free from pits, so a solid metal mirror was not prepared. Furthermore silicon proved to be the most difficult substance to sputter.

† A trade name for a material used by watchmakers for polishing steel parts, probably it is fused borax finely powdered.

One mirror of 45% opacity was finally produced in thirty hours of sputtering in the presence of argon. An attempt at a more opaque mirror failed to go beyond the 45% opacity in one hundred and ten hours of sputtering. In both cases it was proven that aluminum sputters much more readily than silicon, because thick films of aluminum formed in the sputtering apparatus near the aluminum electrode.

Speculum.—The specimens of speculum were furnished by Fecker (Pittsburg) in a highly polished condition. They tarnished, however, before they could be used. In earlier work this was removed by lightly rubbing the surface on which drop chalk was deposited from an alcoholic suspension. Later it was found that light buffing with a rouged chamois gave a good surface. In neither case was it possible to remove the tarnish without leaving a few light scratches.

A speculum blank furnished by Prof. R. W. Wood was used to sputter a speculum mirror on glass. A brilliant surface was produced. This mirror may have departed from the exact percentage composition of the speculum, but it had all the color characteristics of fresh speculum.

*Steel.**—The steel mirror was prepared exactly as described for the steel mirror used as the foundation for the chromium mirror.

*Stellite.**—The specimen of this alloy was polished on a tin lap with fine emery and polished with diamantine on boxwood. The surface was not entirely free from scratches.

Wood's Metal.—An attempt was made to make a mirror of this alloy by pouring the molten metal on plate glass¹² and using the surface of contact without retouching.

Adjustment of Mirrors.—It was necessary to adjust the mirrors carefully to insure that the reflected spectra fell exactly within the diaphragm aperture in front of the plate, and also to make the angle of incidence 45°.

No method of achieving this result was found superior to visual observations on the reflected images from the three mirrors mounted on *M*, each with three separate adjusting screws. Assuming one mirror to be in adjustment, the others were in adjustment with it when a continuous and straight image of a rod was given by the three adjacent mirrors at all angles of incidence. In practice, one old mirror was left in place while two new ones were adjusted. Even

* Polished by Mr. David Mann.

with great care in this adjustment, it was frequently necessary to make small readjustments after test plates had been taken for the reflection of the mirror under consideration.

The exposure of the photographic plates.—With an apparatus as described, the process of finding the reflecting power at any particular wave-length was to photographically record the spectrum when the plateholder was in the P position, and compare its intensity with the intensity when the plate holder was at the P' position and the light was reflected by a mirror.

To obtain trustworthy numerical results this required that the intensity of the source remain constant in value for the series of exposures. The requirement that the pressure of the gas be lower in the main body of the spectrograph than in the discharge tube coupled with the requirement that there be no window covering the slit necessitated the continuous flow of the gas through the discharge tube. A constant intensity source under those conditions was assumed to be one in which the voltage applied was constant and the pressure regulated to yield a constant current. For a well out-gassed tube this proved to be true under most circumstances. The actual regulating of the pressure to comply with the condition of constant current was tedious, but quite possible with the use of the capillary valve described (Fig. 3). In order that the instantaneous values of the current might never vary more than 5% from an assigned average value, it was essential that the author continually adjust and readjust the flow of gas through the capillary valve.

It was likewise necessary to keep the discharge operating throughout the exposure of a single plate to avoid transient fluctuations when the discharge was started. Thus the exposure of the plate was not undertaken until all the factors of pressure, current, temperature and the like had reached approximately equilibrium values.

Actually in some cases the intensity of the source did change slowly during the course of the exposure of a plate. Such fluctuations were not erratic or sudden, but continuous and very gradual. They were particularly evident with the helium 585 Å line where usually there was a slow increase of effective intensity over a series of exposures. It was easy to correct for such cases by repeatedly applying to the plate some convenient direct exposure, and observing the resultant opacities of the photographic images, either in yielding a curve of the variation of intensity with the time, or showing its constancy.

A typical plate would include in the neighborhood of fifteen exposures one above another. These would cover a region of wave-lengths about 400 \AA wide and give data on three different mirrors. After the tube had been out-gassed and then allowed to run for some minutes under conditions chosen for the plate, several exposures would be taken with the plate in the direct (P) position. These would have the same exposure time, but use different apertures of the sectored disk, corresponding to the percentage reflection expected from the mirrors in the apparatus. Next, one of the mirrors would be brought into a reflecting position and the plateholder turned to the P' position (Fig. 1) and exposed for the same length of time as the direct exposures, with the sectored disk out of the path of the light. After the first mirror had been used, one of the direct exposures would be repeated to check the constancy of the source intensity. In turn each of the other two mirrors would be used, with a direct exposure preceding and following each of the mirror exposures.

For each group of three mirrors at least four plates had to be taken to cover the spectral region under examination. Helium was used to produce the 585 \AA line. Oxygen was commonly used for the wave-lengths between 1100 \AA and 1900 \AA , although nitrogen was equally satisfactory. Hydrogen served as a source of intense lines (e. g. 1216 \AA) and was useful in the numerous adjustment plates to bring the mirrors into exactly the right position. Hydrogen also was useful to check up on the wave-lengths present in the nitrogen and oxygen spectra.

Wherever possible several plates were taken on each region to provide additional data and a more accurate result. Unfortunately no data are available on the region between 600 \AA and 1000 \AA , because no gas used presented strong radiation in that region when excited with the direct current discharge.

Photometric measurement of plates.—The measurement of the plates on the thermocouple photometer proceeded according to usual methods. The deflections of the galvanometer were observed for the thermal currents due to the light transmitted by small patches of the plate. For the spectral lines chosen for the calculations, the photographic plate was adjusted in position until the deflection was a minimum. This deflection, the zero point of the instrument, and a deflection representing the energy transmitted by the plate in a neighboring unexposed region were the basis of the calculation of the opacity of the line image. The latter reading on the background

of the plate was taken if possible at such a position that it could correct for scattered light a wave-length different from that under consideration.

IV. PHOTOGRAPHIC PHOTOMETRY.

Correct Usage of Photographic Plate.—The following is quoted by Prof. Lyman¹⁴ from Fabry and Buisson: "The only correct method of using photography is to attempt to produce two images of equal density on the same plate and with the same time of exposure." This would require here that one of the images be produced by light that has been decreased in intensity to a known percentage of its original value; the other should be produced by the full intensity as reflected from a mirror. With equal densities or opacities the percentage reduction used in the first exposure would measure the reflecting power of the mirror.

Unfortunately there was no simple way of reducing the intensity in a known way for light of these wave-lengths. In all the early work with this apparatus the reduction was accomplished simply by varying the exposure time. The reflecting power at a certain wave-length would be the exposure time of the direct, divided by the exposure time of the reflected spectral line of same opacity (multiplied by 100 for percentage reflecting power).

Reciprocity condition and its failure.—This procedure was not completely satisfactory, for it requires that the opacity of a photographic image is simply a function of the product $I t$, where I is the intensity and t the exposure time. This is known as the reciprocity condition, and is known to fail for most emulsions and most wave-lengths except as a first approximation.

The Schwarzschild condition that the opacity is a function of the product $I t^p$, where p is an exponent near unity also fails to represent the facts exactly. Jones¹⁴ and his collaborators have shown that under certain conditions p varies between .84 and 1.10, depending on a large number of variables. They have found a relation (the Kron-Halm formula) that does fit the facts for a large number of emulsions. However, no simple method of deriving the constants for this region was available in the present case.

Harrison's work¹⁵ showed that the oiled photographic plate does obey the reciprocity condition for wave-lengths between 2000 Å and 2600 Å. This was not sufficient evidence, however, to permit the numerical results of this investigation to depend upon reciprocity.

Justification for use of Intermittent Sector Disk.

The apparatus described (Fig. 4) was intended to test whether or not the reciprocity condition holds for wave-lengths shorter than 2000 Å in the case of the oiled emulsion. In addition, it was designed for use in each subsequent measurement of reflecting power.

In a sense however, the sector disk does not reduce the intrinsic intensity of the beam but merely permits its passage for a certain percentage of the time. It is necessary to justify its use as a means of reducing the intensity of the light.

Davis¹⁶ has treated the intermittent sector disk and evaluated the "intermittency errors." However, his conclusions do not apply directly here. He contrasted the opacity produced by an intermittent source and a continuous source using the same intensity and actual net time of exposure. In my work, the comparison is to be made between two exposures of the same total elapsed time of exposure, the one at reduced intensity, the other with full intensity but with an intermittent sector rotating to reduce the effective intensity. There is a distinct difference between his case and mine, so it is fundamentally necessary when thinking of intermittency errors to inquire which type of comparison is being made.

Bureau of Standards workers¹⁷ have found the sector disk as employed here satisfactory and in agreement with other valid methods down to 2500 Å. Baker¹⁸ came to the conclusion that the sector disk is accurate to 1% in reducing the intensity for photographic work with visible light so long as the flashes produced by the disk occur as often as sixty times per second. It is difficult to understand why one particular speed should mark, as it did, the boundary for all emulsions where the disk became accurate to 1%; it would seem more reasonable if the boundary line depended upon the intensity of illumination used. However, I followed Baker, using exactly sixty flashes per second.

Baly, Morton and Riding¹⁹ have compared the results obtained when an intermittent sector disk is used with those obtained by accepted valid methods. They worked in the ultra-violet to 2500 Å and found the two methods checking to within the accuracy of their experiment, namely two or three per cent.

The intermittent method of reducing intensities has been compared with calibrated screens by Weinland.²⁰ In every case he found that the curves of opacity against intensity given by intermittent methods lay between those given by reciprocity and those obtained with the

calibrated screens, and nearer the latter. Evidently, the sectorized disk as employed in my work is a great improvement over the use of reciprocity as a method of obtaining numerical results from a photographic plate.

V. CALCULATIONS.

The computation of the reflecting power required that the opacity of the reflected image should be matched exactly with the opacity of a direct image. To this end a number of different wave-lengths were chosen, and for each a graph was drawn of opacity against the percentage aperture used in the direct exposures which were all of the same exposure time. The opacities of the corresponding wave-length lines in reflected spectrum could then be used to determine what percentage aperture would be required on the sectorized disk to match exactly the reflected spectral line of that wave-length. Repeated for each wave-length under consideration this yielded the numerical reflecting power as a function of the wave-length for the range of wave-lengths covered by the particular plate.

A large part of the work was accomplished without the direct use of the sectorized disk. The calculations in those cases consisted in plotting the opacities for a given spectral line against the exposure times producing them. Then with the opacity found for the reflected line of that wave-length, the exposure time of direct exposure could be read off the curve which would produce the same opacity of photographic image as that reflected line. Assuming the reciprocity condition, the reflecting power at that wave-length was the ratio of direct exposure time to the reflected exposure time (multiplied by 100 to give percentage reflecting power).

After the reflecting power for each mirror had been tabulated and averaged at the individual wave-lengths, then an average correction was applied as calculated from twelve plates taken to test the reciprocity condition.

These test plates compared the opacity of lines produced by a direct exposure using the full intensity of the source, with the opacity of lines produced by a direct exposure with the disk operating and the exposure time correspondingly increased. For example, if the 25% opening of the disk was effective then the exposure time was quadrupled. At a particular wave-length, the ratio between these two opacities averaged over a number of plates and taken under various conditions yielded an approximate percentage correction

which was applied to the average values of the reflecting power obtained. In addition, these data on the departure from reciprocity were translated into a more familiar form by the computation of the exponent p of the Schwarzschild formula. These average values of p permit comparison of the departure from reciprocity in this region with results obtained in the near ultra-violet and the visible. Furthermore, they show the variation from wave-length to wave-length in the extreme ultra-violet.

VI. SOURCES OF ERROR.

The chief sources of error in this work are as follows: (1) intermittency errors; (2) fluctuation in the intensity of the source of light during the exposure of a plate; (3) variations in the sensitivity of the oiled photographic plate over the area of a single plate; (4) variations in the absorption of the residual gases in the spectrograph; (5) errors introduced by scattered light reaching the mirrors and plate of wave-lengths different from those under consideration; (6) inaccuracies in the photometric measurement of the plates.

The errors due to the inadequacy of the sectored disk as a means of reducing the intensity should be less than 3% according to the work cited of other observers. These errors are, in contrast to the others of this list, distinctly instrumental; i. e. no amount of averaging of a large number of observations can reduce the magnitude of the probable error due to this cause. They are greater in this work than necessary because corrections for lack of reciprocity were performed approximate where the sectored disk had not been actually used in the exposure of the plate from which the reflecting power data were taken.

It was impossible, in general, to distinguish between sources (2), (3), and (4). The second and fourth have been actually observed where the manipulation of the apparatus had not been up to standard. No direct experiments were made on the variation in the sensitivity of the plates over their areas, but such small plates were used, with comparisons of images not more than one or two centimeters apart, that little trouble was expected from this cause.

Scattered light was bothersome when the spectrographic slit was not clean and when the mirror under examination did not have a good optical surface.

It is difficult to estimate the magnitude of the errors of the photometer used in the measurement of the plates. It would vary with the zero shift of the instrument at the particular time and also depend

upon the condition of the photographic plate itself. On the average, its readings were probably good to 3%.

It is possible that single observations on the reflecting power at an isolated wave-length might contain a 10% error. However, with repeated measurements, and with curves averaging the values at neighboring wave-lengths and thus smoothing out the curves, the values given of the reflecting power must be valid to better than 5%. Except for the instrumental error of source (1) still better accuracy might be claimed. For example, the reflecting power of platinum at 585 Å measured on three separate plates 18.5, 18.6, and 18.8%. These would give a probable error of less than 1%.

VII. RESULTS.

Photographic Photometry with the Oiled Photographic Plate.

Direct tests on the behavior of the photographic plate conducted with the sectored disk reveal departures from the reciprocity condition. These are important in some cases, and at other wave-lengths are so small as to be negligible compared to errors from other causes.

The tests were self-consistent in nearly every case in spite of being applied under various conditions on different plates. Some departures from reciprocity of but 1% seemed so persistent in reoccurrence as to be recorded as significant.

By reference to the Schwarzschild condition that the opacity is a function of $I t^p$, the average value of p was computed for each wave-length considered, and is plotted in Figure 5. Although I have connected the points by a curve, the connecting curve may, or may not, have any meaning as to the value of p at the intermediate wave-lengths.

A value of p greater than unity at any wave-length indicates that if the reciprocity condition were used in computing the reflecting power, the resulting numerical value would be greater than the true value. Conversely when p is less than unity the reciprocity value for the reflecting power is too low.

In general the departures vary at a given wave-length with the opacity as shown by Jones.¹⁴ It was quite evident that in most cases a greater opacity was accompanied by a larger value of p . The values given in Fig. 5 are average and are intended to be for the opacities actually used in the reflecting power measurements.

The value of p at 1216 Å is larger than at other wave-lengths and

the higher value of p seems to persist even for low values of the opacity.

The behavior at the 1151 Å (oxygen) line is most exceptional. Even for high opacities of the photographic image the value of p drops to the lowest value observed. Just what can be the explanation is not evident, but the effect may be caused by the fluorescent action of the sensitizing oil.

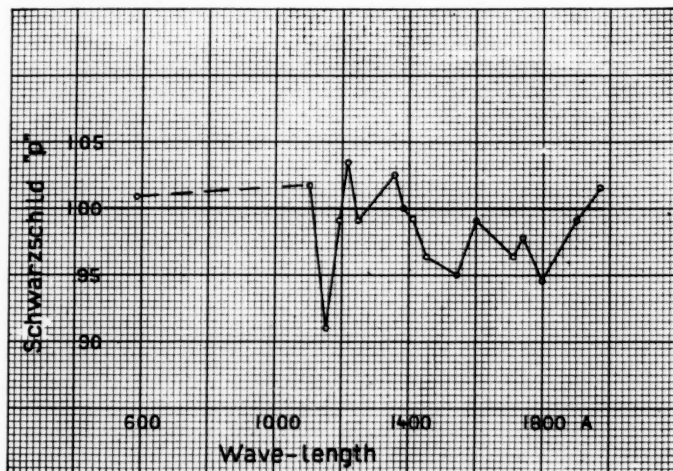


FIG. 5.

Applying the correction indicated at 1151 Å and 1216 Å has served to smooth out the reflecting power curves in that region. When reciprocity was assumed the curves for all materials showed a dip downwards at 1151 Å and up at 1216 Å, the corrections have made the results seem more reasonable in that the values at those two neighboring wave-lengths became very nearly the same. On some curves the former effect is still evident, probably because the corrections were not exact.

It is clear that the value of p is near enough unity at certain wave-lengths so that this oiled photographic plate might be used at those wave-lengths under the assumption of the reciprocity condition. In

general, however, wherever an accuracy better to that 5% is sought these departures from reciprocity can not be neglected. The only valid method must still be one where known reductions of intensity are applied to each and every plate used in the measurements.

Reflecting Power Results.—The results to be given cover the seventeen substances and twenty-five mirrors investigated. With minor exceptions, the qualitative work of Gardner² agrees with my work. In general, the numerical values at 1850 Å given by Hulburt⁶ are higher than mine.

Pfund's work³ agrees with the values given here for crystalline quartz, glass, speculum and silver while there is some disagreement on gold and platinum. The work of Lewis and Hardy⁵ near 1850 Å is consistent with my results for the metals they studied. Their values for the reflecting powers of other materials do not agree with mine.

While I paid considerable attention to the value of the reflecting power at 585 Å, the shortest wave-length reached, still the exact shape of the reflecting power curves at that point is unknown. This is unavoidable inasmuch as no suitable source was available for wave-lengths between 585 Å and 1000 Å. The curves are drawn with broken lines in that region to remind the reader of that fact. The reflecting power continues to decrease with shorter wave-lengths.

Aluminum.—The reflecting power curve of a sputtered aluminum surface is shown in Fig. 6. At 585 Å it shows a 5% reflecting power which apparently remains constant until 1400 Å, from which wave-length it rises to 14% at 1850 Å.

These values are consistent with Gardner's conclusions. Hulburt's value of 23% at 1850 Å is much higher than mine. Nutting's²¹ prediction of a 65% reflection at that point must be in error.

Beryllium.—The reflection of a sputtered beryllium surface is shown in Fig. 9. The work of Coblenz and Stair²² gives a 57% reflecting power for beryllium at 2500 Å with a curve that rises towards shorter wave-lengths. My work, however, reports a relatively small reflecting power at 2000 Å and shorter wave-lengths. Beryllium is unique in showing a deep minimum in reflection at 1640 Å. Its reflecting power is increasing towards the shorter wave-lengths rising to 9.9% at 585 Å.

With only a reflecting power of one per cent at 1640 Å, according to classical reflection formulae the index of refraction must be nearly unity at that point and k , the absorption coefficient must be

small. Probably the index of refraction of beryllium is passing through the value unity at that wave-length. If that is the case, then k is 0.27 there.

Brass.—The reflecting power (Fig. 7) of brass polished on jasper remains at a low value throughout the extreme ultra-violet. At 585 Å it is 5%, falling to 4.1% at 1216 Å, rising to 7% at 1600 Å and falling again to 5.9% at 1850 Å. Nutting²¹ gave a value of 65% at that wave-length.

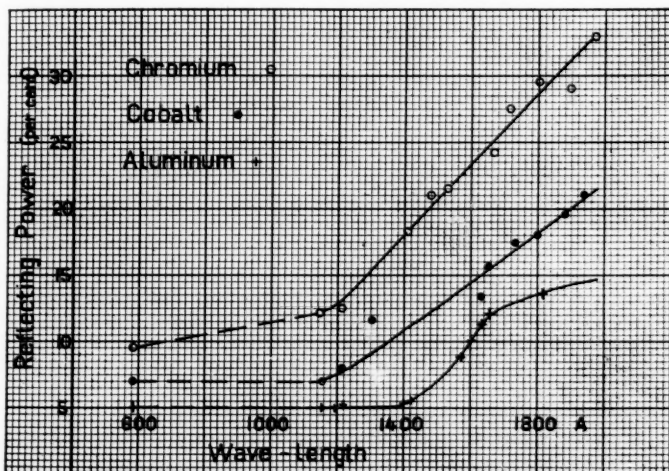


FIG. 6.

Chromium.—The reflecting power of the chromium mirror (Fig. 6) (electrolytically deposited on steel and touched up with diamantine) is 9.6% at 585 Å, rises to 13% at 1216 Å and at wave-lengths longer than 1400 Å has a higher reflecting power than any substance studied. At 1850 Å my value of 30% checks Hulburt's value. Coblenz and Stair²² not only report a high reflecting power for chromium in the ultra-violet but find that it retains this property even after prolonged exposure to ultra-violet light.

Cobalt.—The reflecting power of a mirror of cobalt metal (Fig. 6) varies from 7% at 585 Å to 7.8% at 1216 Å to 19.0% at 1850 Å.

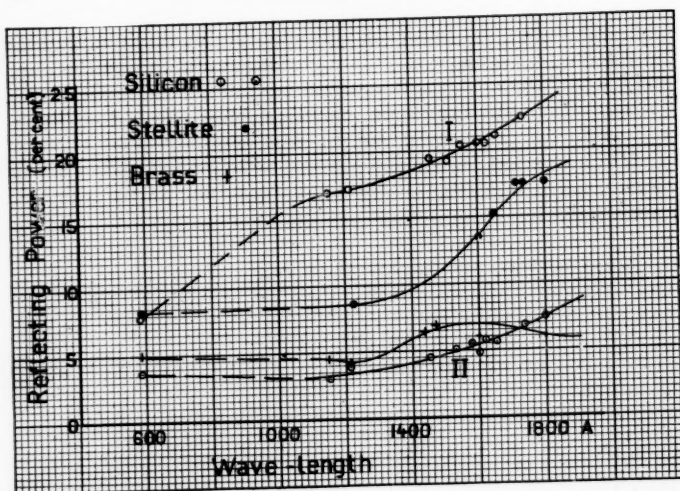


FIG. 7.

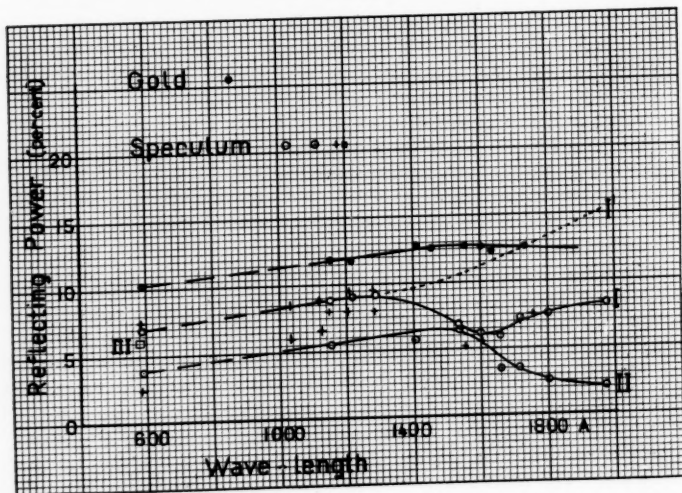


FIG. 8.

This latter figure is much less than the 30% figure of Hulburt's at that wave-length.

Gold.—The sputtered gold mirror (Fig. 8) has a high reflecting power at 585 Å of 10.3%. However it does not increase above 12.8% in the entire region. My work agrees with Gardner that gold is superior to speculum particularly at the shorter wave-lengths. Hulburt ascribed a reflecting power of 14% to gold at 1850 Å compared with 12.5% in my work. Pfund's value of 6.3% is much less than the 12% for the same region in my work.

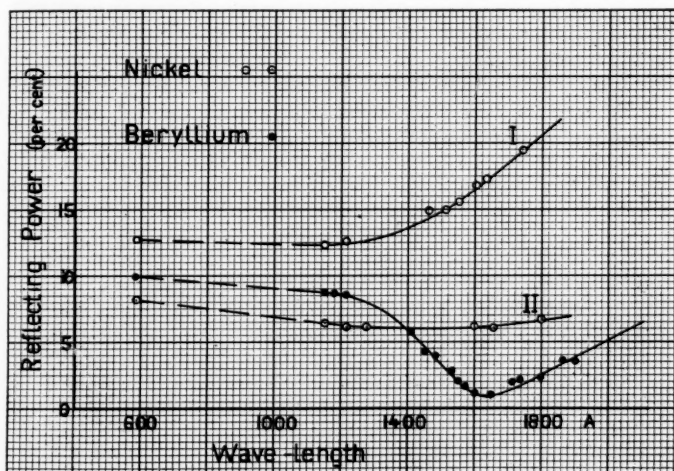


FIG. 9.

Nickel.—The results on two sputtered nickel mirrors are shown in Fig. 9. The value of 12.6% for the reflecting power at 585 Å gives fresh nickel (curve I) the position second to platinum among the best reflectors at that short wave-length. Even the two year old sputtered film (curve II) possesses a reflecting power of 8.0% at 585 Å which is as good as the best speculum surface observed. Since the shape of curve II is different from that indicated in curve I it is likely that the sputtered film had oxidized in its long exposure to the air.

Gardner gave nickel a slight superiority over speculum at his shorter wave-lengths, which is true here. Hulburt's value of 28% at 1850 Å is rather higher than my 21.5%.

Platinum.—Four different sputtered platinum mirrors are covered in the data of Fig. 10. Curve *I* is for a fresh, bright surface and at shorter wave-lengths is far superior to any other mirror studied. This value of 18.6% at 585 Å was checked repeatedly and is the average of data from five plates. When the attempt was made to check this result on another surface, freshly sputtered, a good bright

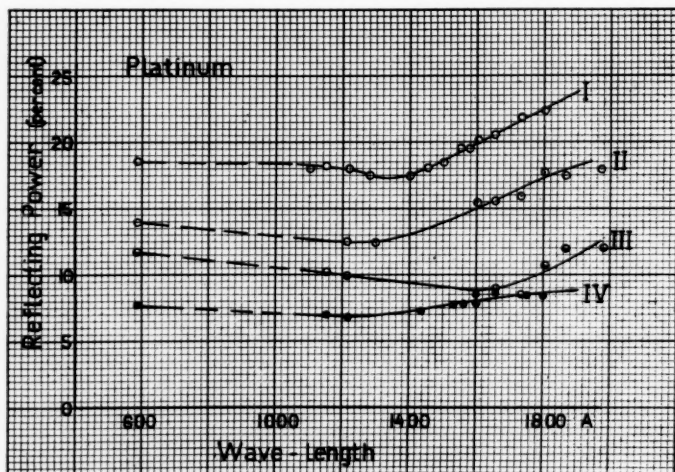


FIG. 10.

surface was not obtained. But even the curve for that mirror (curve *II*) is parallel to the first and the numerical values are much higher than for other materials. Curve *III* covers a mirror sputtered at the same time as the second specimen but on which a bluish film had formed due probably to the fuming of the soft wax with which it was mounted. Curve *IV* is for a surface sputtered nearly two years prior to the time of this test, and spotted accidentally at that time with phosphorus pentoxide. Even with that abuse, its reflecting power at 585 Å is as high as for the best speculum!

It is interesting to note that the first successful test of reflecting power taken with this apparatus was made with the mirror of curve *IV* when it was new and unspotted and at the wave-length 585 Å. No accurate means of controlling the intensity were available, but an attempt was made to keep the average intensity constant over the very long exposures then taken. After a year had passed, the plate was run through the photometer and the estimate made that the reflection at 585 Å would be 18.4%. This compares very favorably with the careful measurements ten months later giving the value 18.6%. There was some evidence on the early plate, which recorded the 738 Å line of neon, that platinum has a maximum in its reflecting power between 600 Å and 1000 Å rising to 25% in that region. This has not been verified.

Gardner's conclusion that the reflecting power of platinum is increasing with respect to speculum for wave-lengths shorter than 1200 Å agrees with my work. Pfund's value of 8% for the spectral region he investigated is much lower than the 18% on my curve *I*. At 1850 Å the value here is 23.5% whereas Hulburt gave 31% and Lewis and Hardy 21%.

Silver.—It is well known that silver tarnishes rapidly under exposure to ultra-violet light. The same effect here made it practically impossible to get results on a fresh surface. By the time an adjustment plate could be taken the specimen was no longer fresh. Fig. 11 gives my interpretation of the data. Curve *I* is intended to describe the reflection of a fairly fresh surface, the dotted portion of it is unsupported by experiment. Curve *II* is for the same surface in a badly tarnished condition, due almost entirely to its exposure to the extreme ultra-violet during adjustment and measurements.

This work agrees with Gardner's in showing silver to be a poor reflector in this region. Pfund's value of 5.1% for the wave-lengths just short of 1200 Å is exactly the value on curve *I*. Hulburt's value of 18% at 1850 Å compares with 12% on curve *I* and 7.5% on curve *II*.

Silicon.—Two silicon mirrors were measured (Fig. 7). One was freshly sputtered (curve *I*) while an old mirror on glass of uncertain origin was also tested (curve *II*). The latter was not very clean nor was the silicon film very thick. The new film (curve *I*) gives a reflecting power of 7.8% at 585 Å and rises rapidly to 17% at 1200 Å and 24% at 1850 Å.

The qualitative statement of Gardner is verified that silicon reflects

about twice as well as speculum at the longer wave-lengths and falls to almost the level of speculum at 1100 Å. Hulburt's value of 60% at 1850 Å is very much greater than my value. Lewis and Hardy's value of 31% is closer to mine. A thicker film or a good solid mirror might give higher values than mine.

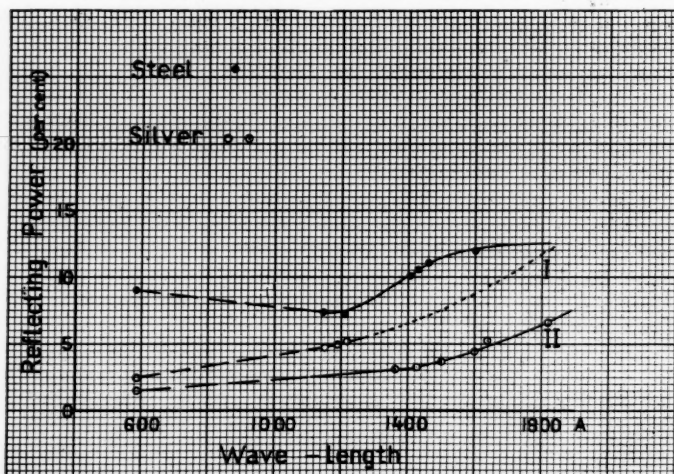


FIG. 11.

Speculum.—Reflection by speculum mirrors from Fecker was given considerable study (Fig. 8). Particular attention was given the reflection at 585 Å. Values all the way from 2.5% to 7.5% were obtained there. Such variation could entirely be accounted for by the tarnishing of the surface. Even a freshly sputtered surface gave a reflection of but 6% at 585 Å. This point is indicated by the square and marked *III*.

The first Fecker mirror was first measured in a tarnished condition and was then repolished a number of times. An average of some of the data on it is indicated by the crosses. At 585 Å only extreme values are shown. Curves *I* and *II* are for the second mirror from Fecker. Curve *I* gives the data for it freshly polished, but slightly tarnished with a light bluish film caused probably by the fuming of

the soft wax mounting. Curve *II* is for the same mirror two weeks after polishing on which the tarnish was very apparent. The dotted curve *I'* is drawn to estimate the reflecting power for clean polished speculum. This is not supported by direct experimental data except the evidence from curves *II* and *III* of platinum.

Curves *I* and *I'* correspond to Gardner's comparison of speculum to other substances. Hulburt's results are in accord with these since he found values ranging from 20% to 4% at the 1850 Å wave-length. Lewis and Hardy's result of 10% at that wave-length is in accord with curve *I*. Pfund's value of 5.3% for the wave-length region just below 1216 Å conforms very closely to the values of curve *II*.

Steel.—The reflecting power of steel (Fig. 11) decreases from 9% at 585 Å to 7.2% at 1216 Å and then rises to 12.2% at 1800 Å. This corresponds to Gardner's statement that steel is equal to or better than speculum at the longer wave-lengths, but inferior at the shorter. However, at the still shorter wave-length employed here steel becomes again superior. Hulburt found a value of 16% for steel at 1850 Å compared to mine of 13%.

Due to adjustment difficulties, these data are the results of single observations and are not to be considered as up to the usual accuracy of this work.

Stellite.—The stellite mirror (Fig. 7) shows a reflecting power of 8.3% at 585 Å rising to 8.6% at 1216 Å and then to 18.2% at 1800 Å. This compares favorably with Gardner's conclusion that stellite is a better reflector than speculum. Hulburt's value of 30% is much greater than mine of 18.6% at that point.

The fact that the reflecting power curve for stellite is almost the same as for cobalt may indicate that cobalt must be the constituent of stellite playing the important role in its reflecting power.

Wood's Metal.—No numerical data were obtained upon the mirror of this alloy. I wished to test roughly its reflecting power because of the high value given at 2573 Å by Meier.¹² A single plate was taken in the region of 1200 Å. It was evident from that plate that the reflecting power there is not more than 8%.

Materials other than metals were tried to test the modern grating materials of glass and quartz. A test was made of fluorite because its index of refraction is known in this region.

Fluorite.—Despite the fact that the reflection from the specimen of fluorite was very faint and hazy in the visible, it was finally placed in adjustment. The reflected spectra were all rather fuzzy as a

result of the scratches and possible lack of flatness of the surface. It is not surprising to find low reflection in the extreme ultra-violet.

Both the photometer and the eye detected the fact that fluorite reflects very much better in the region around 1100 \AA than at longer and shorter wave-lengths. The reflecting power curve without correction for the fuzziness of the reflected spectral lines is shown in Fig. 12. The maximum occurs at 1125 \AA with a value of 6.3%. The reflecting power falls to 2.8% at 1850 \AA and 3.0% at 585 \AA .

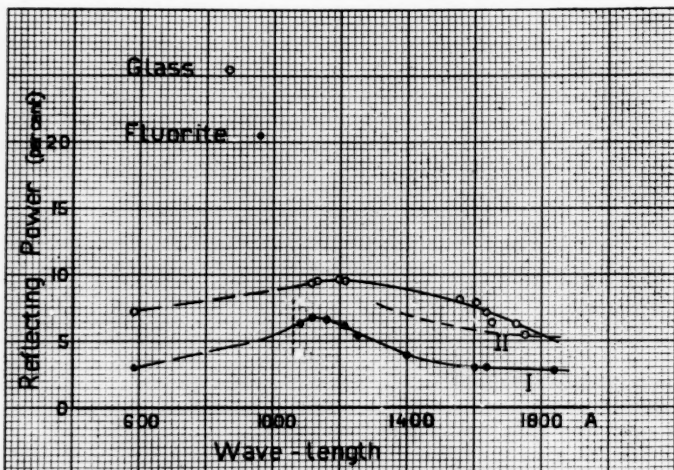


FIG. 12.

A dispersion curve²³ to fit index of refraction data requires an absorption band at 1056 \AA . Depending upon the value of the absorption coefficient, we would expect a maximum in the reflecting power at some wave-length just longer than 1056 \AA . This is consistent with the observed maximum at 1125 \AA .

Handke²⁴ has computed the index of refraction of fluorite down to 1311 \AA . Assuming equal parallel and perpendicular polarization components incident on the mirror, it is possible to apply Fresnel's reflection formula and compute the reflecting power for 45° incidence. I have plotted it as curve II shown as a broken line. This is very

closely parallel to the experimental curve, and as might be expected the experimental curve falls below the theoretical curve.

Lewis and Hardy reported an 8% reflection at 1850 Å whereas the theoretical curve gives 5.5% and my experimental value is 2.8%. Lewis and Hardy ascribed their deviation from theory to a high value of the absorption coefficient which would invalidate Fresnel's formula. Both the fact that fluorite is very transparent at that point, and the fact that Fresnel's formula gives a curve so near to the shape of mine would indicate that their explanation was incorrect.

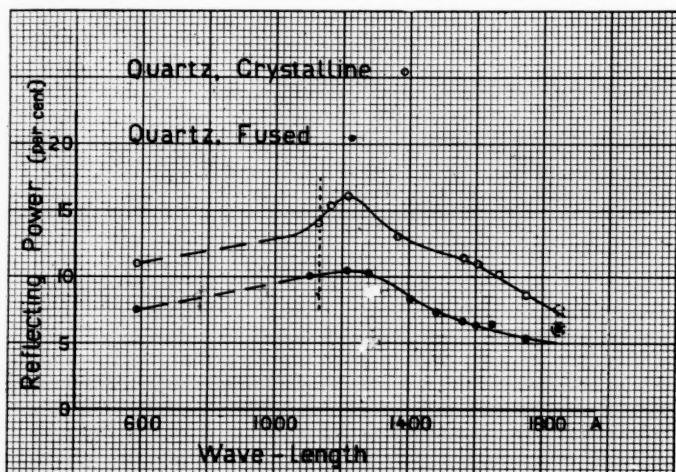


FIG. 13.

Glass.—The reflecting power of glass (Fig. 12) rises from 7.3% at 585 Å to 9.6% at 1200 Å and drops to 5.1% at 1800 Å.

Pfund's value of 8.5% for the wave-lengths just short of 1200 Å is lower than mine which go from 8.9% at 1000 Å to 9.6% at 1200 Å. Lewis and Hardy give 13.5% reflection for "ordinary glass" at the 1850 Å region. My value of 5.0% is clearly lower.

Quartz.—The reflecting power of crystalline quartz (Fig. 13) starts at 11.0% at 585 Å and increases to 16.0% at 1216 Å and then decreases to 8.0% at 1800 Å. Fused quartz behaves similarly with

lower values throughout. It varies from 7.5% at the lower wave-length to a maximum of 10.5% and drops to 5.2% at 1800 Å.

TABLE I.
REFLECTING POWER IN PER CENT.

| Substance | Wave-length | | | |
|------------------------------|-------------|--------|--------|--------|
| | 585 Å | 1150 Å | 1500 Å | 1800 Å |
| Aluminum | 5.0 | 5.0 | 7.0 | 13.5 |
| Beryllium | 9.9 | 8.7 | 3.4 | 2.5 |
| Brass | 4.9 | 4.5 | 6.8 | 6.0 |
| Chromium | 9.6 | 12.2 | 20.7 | 28.5 |
| Cobalt | 7.0 | 7.0 | 12.3 | 17.0 |
| Fluorite | 3.0 | 6.7 | 3.3 | 2.8 |
| Glass (spectacle lens blank) | 7.3 | 9.1 | 8.4 | 5.3 |
| Gold | 10.3 | 11.8 | 12.8 | 12.5 |
| Nickel freshly sputtered | 12.6 | 12.2 | 14.7 | 20.5 |
| old sputtered | 8.0 | 6.3 | 6.0 | 6.5 |
| Platinum freshly sputtered | 18.6 | 18.2 | 18.6 | 22.1 |
| imperfect freshly sputtered | 13.9 | 12.6 | 13.8 | 17.2 |
| tarnished sputtered | 11.7 | 10.2 | 9.0 | 10.2 |
| old and spotted sputtered | 7.8 | 7.0 | 7.8 | 8.8 |
| Quartz, crystalline | 11.0 | 14.9 | 11.8 | 8.0 |
| Quartz, fused | 7.5 | 10.3 | 7.1 | 5.2 |
| Silver fresh | 2.5 | 4.8 | | |
| after exposure | 1.5 | 2.7 | 3.7 | 6.0 |
| Silicon freshly sputtered | 7.8 | 16.9 | 19.4 | 23.3 |
| old | 3.7 | 3.2 | 4.7 | 7.5 |
| Speculum fresh | 7.5 | | | |
| sputtered | 6.0 | | | |
| badly tarnished | 2.5 | | | |
| light tarnish | 3.8 | 5.5 | 6.8 | 2.5 |
| repolished | 7.0 | 8.8 | 7.3 | 7.5 |
| Steel, carbon tool | 9.0 | 7.4 | 11.4 | 12.7 |
| Stellite | 8.3 | 8.5 | 11.2 | 18.2 |
| Wood's Metal | | 7 (?) | | |

In the case of quartz, we have the value of the index of refraction only to 1850 Å. This gives a numerical check with theory only at that point. By applying the Fresnel formula for the reflection of transparent substances (assuming equal polarization components) I find that crystalline quartz should have a reflection of 7.5%, whereas

my data give a value of 7.2%. With fused quartz the agreement is not quite so good: a theoretical value of 6.1% as against 5.0% by experiment.

Dispersion formulae have been fitted to the values for the index of refraction of crystalline quartz.²⁵ These require the introduction of an absorption band at 1130 Å. This wave-length is shown by the vertical dotted line in Fig. 13. The maximum in the reflecting power at 1220 Å satisfies the condition that there should be a maximum in reflection at the long wave-length side of the absorption band.

Pfund's value of 13.5% agrees with mine for crystalline quartz in that my curve rises from 13.0% at 1025 Å to 16.0% at 1216 Å. Lewis and Hardy's value of 10% at 1850 Å is greater than my value of 7.0%.

My results are a confirmation of Prof. Lyman's²⁶ conclusions in regard to the relative reflection of glass, quartz and speculum when used in gratings. He found glass and quartz superior to speculum at the shorter wave-lengths. He indicated that quartz was hardly any better than glass. Since his tests were on a grating ruled on fused quartz, his practical work agrees with my measurements.

VIII. CONCLUSIONS.

It is quite evident that a number of factors affect the values of the reflecting powers of substances and their variation with the wave-length. Clearly surface conditions are important and are particularly potent in reducing the absolute value of the reflecting power, and in changing the shape of the curves as functions of the wave-length.

This variation with surface conditions is amply illustrated by the results on speculum (Fig. 8), silver (Fig. 9) and platinum (Fig. 11). In the case of speculum and platinum the effect was partly due to the fuming of the heated soft wax used in mounting the mirrors. This same soft wax was extensively used in the apparatus for the sealing of flange plates and windows to the spectrograph. Probably the slow fuming at ordinary temperatures accounts for a part of the tarnishing of a speculum grating in use.

An attempt was made to discover which ingredient in this soft wax was responsible. As far as visual observations could tell, the bees wax and the Venice turpentine were equally guilty when permitted to fume at equal temperatures on equally well polished speculum mirrors.

The arrangement of the molecules in a substance may be of prime

importance in determining the value of the reflecting power in the extreme ultra-violet, whereas the nature of the molecules may determine the shape taken by the curve of reflecting power against wave-length.

This is shown by the relation between the curves for crystalline quartz and fused quartz. Both are SiO_2 and the shapes of the curves are quite similar. However the arrangement of the molecules in the two cases is different and my curves show that crystalline quartz is superior at all wave-lengths.

Even in mixtures of various materials it seems that one of the constituents is inclined to dictate the shape of the reflecting power curve. In my results this is shown by the similarity of the curves for glass and fused quartz and for stellite and cobalt.

This work coupled with that of Pfund's⁴ gives strong evidence for the fact that dispersion formulae of transparent substances determine with fair accuracy the positions both of the absorption bands and the maxima in the reflecting power of these substances. On this basis, diamond should not only have a maximum in its reflecting power in the neighborhood of 1400 \AA , but should (due to its high index of refraction) have a higher reflecting power than any other substance studied at these wave lengths.

The comparative data on reflecting power are shown in Table I. It is seen that platinum is the best reflector at the shorter wave-lengths with nickel, crystalline quartz and gold following in order. On account of the great permanence of a polished surface of chromium and relatively good reflecting power, it should be a useful reflecting material in this region.

The photometric work with the oiled photographic plate has shown that the reciprocity condition may be depended upon for approximate results but that it can not be used in more accurate work.

I wish to express my gratitude to Mr. David Mann, chief mechanic of the Jefferson Laboratory for his careful work in the preparation of the apparatus for this undertaking.

It is a pleasure to thank Prof. Lyman for suggesting this problem and maintaining a constant and helpful interest in all its details.

REFERENCES.

- ¹ Gleason, P. R., *Proc. Natl. Acad. Sci.*, 15, p. 551, 1929.
- ² Gardner, I. C., *Astrophysical J.*, 45, p. 30, 1917.
- ³ Pfund, A. H., *Jour. Opt. Soc. America*, 12, p. 467, 1926.
- ⁴ Pfund, A. H., *Phys. Rev.*, 32, p. 39, 1928.

- Lewis, E. P. & Hardy, A. C., Phys. Rev., 14, p. 272, 1919.
- ⁶ Hulburt, E. O., Astrophysical Jour., 42, p. 205, 1915.
- ⁷ Lyman, Theodore, Spectroscopy of Extreme Ultra-violet, 2nd edition, p. 38.
- ⁸ Lyman, Theodore, Spectroscopy of Extreme Ultra-violet, 2nd edition p. 42.
- ⁹ Lyman, Theodore, Spectroscopy of Extreme Ultra-violet, 2nd edition p. 48.
- ¹⁰ Lyman, Theodore, Spectroscopy of Extreme Ultra-violet, 2nd edition, p. 61.
- ¹¹ Stetson, H. T. & Carpenter, E. F., Astrophysical Jour., 58, p. 39, 1923.
- ¹² Meier, W., Ann. d. Phy., 31, p. 1017, 1910.
- ¹³ Lyman, T. Spectroscopy of Extreme U-V, p. 6.
- ¹⁴ Jones, L. A. & c. Series culminating in Jour. Opt. Soc. America, 14, p. 223, 1927.
- ¹⁵ Harrison, G. R., Jour. Opt. Soc. Am., 11, p. 341, 1925.
- ¹⁶ Davis, R., Bureau of Standards Sci. Papers, Bulletin No. 528.
- ¹⁷ Bureau of Standards Sci. Papers (No. 440) 18, p. 121, 1922.
- ¹⁸ Baker, E. A., Optical Convention Proc. p. 238, 1926.
- ¹⁹ Baly, E. C. C., Morton, R. A. & Riding, R. W., Proc. Roy. Soc. Lond., 113, p. 709, 1927.
- ²⁰ Weinland, C. E., Jour. Opt. Soc. Am., 15, p. 337, 1927; *ibid*, 16, p. 295, 1928.
- ²¹ Nutting, P. G., Phys. Rev., 16, p. 129, 1903.
- ²² Coblentz, W. W. and Stair, R., Journal of Research, Bur. of Standards, Feb. 1929.
- ²³ Lyman, T., Spectroscopy of the Extreme U-V, p. 69.
- ²⁴ Lyman, T., Spectroscopy of the Extreme U-V, p. 69.
- ²⁵ Coode-Adams, W. R. C., Proc. Roy. Soc., 117, p. 209, 1928.
- ²⁶ Lyman, T., Spectroscopy of the Extreme U-V, p. 51.



